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Large grazing birds and agriculture—predicting field use of common cranes and implications for crop damage prevention

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ABSTRACT

Increasing numbers of previously threatened large grazing birds (cranes, geese and swans) are causing crop damage along their flyways worldwide. For example, the number of reported incidents of crop damage caused by common cranes *Grus grus*, followed by regulated inspections and governmental compensation in Sweden, has increased over the last few decades and was valued at ~200,000 Euros in 2012. Consequently, their impact on agriculture is escalating which raises the need for evidence-informed preventative strategies. We surveyed arable fields for autumn staging common cranes in an area surrounding a wetland reserve in Sweden. We assessed the following factors in relation to the probability of cranes being present on fields: crop stage, crop type, distance to roost site, time of day, field size and time since harvest. Stubble fields had the highest probability of crane presence, progressively decreasing through grassland and grazing grounds, bare soil to growing crop. A stubble field at 5 km from a roost site had a predicted probability (95% CI) of hosting cranes of 0.25 (0.19–0.32). The probability of cranes visiting a field was linearly and negatively related to distance to the roost site. For example, the probability of crane presence increased from 0.05 (0.03–0.07) to 0.09 (0.06–0.15) when distance decreased from 5 to 1 km. At stubble fields, the probability of crane presence decreased with time since harvest and was highest for barley with progressively lower probability on wheat and oat. Illustrative scenario predictions developed from the models demonstrated that probability of crane presence could be high, 0.60 (0.42–0.77), if all favorable factors were combined (e.g. barley stubble, 1 day after harvest, 1 km from roost site). Given the existing framework of international conventions and prohibition of culling, there is a need for preventative strategies to reduce crop damage. Based on our results, such strategies should focus on providing cereal stubbles as diversionary fields, especially close to wetland roosting sites. Stubble field availability can be achieved by careful crop rotation planning. We suggest that crop rotation and time of harvest should be added to flyway management plans recently developed for some large grazing bird species to facilitate stable co-existence between conservation practices and agricultural interests.

1. Introduction

Increasing populations of large grazing birds such as cranes *Gruidae*, geese *Branta, Anser* and swans *Cygnus*, aggregate and forage on arable land in large numbers at staging sites along their flyways in Europe and North America (Amano et al., 2008; Le Roy, 2010; Sugden et al., 1988), which in turn may cause significant crop damage and economic losses (Heinrich and Craven, 1992; Lane et al., 1998; Lorenzen and Madsen, 1986). For example, the number of autumn staging common cranes *Grus grus* in Germany increased from 45,000 in 1987 to 225,000 in 2008, the number of geese in NW Europe increased by 24%, from about 3.5 million to 4.3 million between 1995 and 2008 and whooper swans *Cygnus cygnus* in Sweden increased from 2000 to 8000 individuals from 1970 to 2000 (Fox et al., 2010; Harris and Mirande, 2013; Mewes et al., 2010; Nilsson, 2002). The number of fields and farmers affected by damage from large grazing birds has increased as have costs for crop damage and preventative measures, for example, farmers have been compensated with ~190,000 Euros (in total 2005–2008) in Lake Der-Chantecoq, France (Salvi, 2010) and ~200.000 Euros (2012) in Sweden for damage caused by common cranes (Karlsson et al., 2013). These population changes, along with increasing crop

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damage are the result of international agreements banning hunting and promoting habitat conservation (e.g. wetland restorations). These include the Convention on the Conservation of Migratory Species of wild animals (CMS), and within Europe, the EU Council Directives on the conservation of wild birds (2009/147/EC) and on the Conservation of natural habitats and of wild fauna and flora (92/43/EEC), as well as species-specific flyway management plans (Madsen and Williams, 2012). Additionally, these species have benefitted from the EU Common Agricultural Policy (CAP) that has promoted intensified agricultural practices with greater use of autumn-sown crops and larger field units (Jongman, 2002; Stoate et al., 2001). As a consequence of non-overlapping objectives between conservation and agriculture, we are now in the situation that the number of large grazing birds continues to increase and fuelling for a potential conflict between those aiming to maximize agricultural production and those aiming to conserve biodiversity (MacMillan and Leader-Williams, 2008; Redpath et al., 2015, 2013).

Damage to agriculture is commonly severe in the vicinity of protected wetlands, because they provide attractive roost and staging sites for large grazing birds (Kleijn et al., 2014; Vegvari and Tar, 2002), while the birds' resource needs are not often fulfilled within protected areas (Fox and Madsen, 1997; Woodroffe, 1998). Consequently, birds use agricultural land surrounding protected areas for foraging, causing crop damage (Alonso et al., 1983; Amano et al., 2007; MacMillan et al., 2004; Nowald, 2010). Damage to crops leads to complex secondary effects, such as reluctance from certain stakeholders to react positively to the introduction of new protected areas or other conservation initiatives, potentially hindering the effective conservation of other bird species or important environments (Dickman, 2010).

Management strategies can be developed following assessment of the probability of birds visiting different types of fields. Strategies should aim to reduce crop damage and its costs by steering birds to less damage-prone or less valuable fields, such as harvested or diversionary fields and to predict where high damage risk might occur (Jensen et al., 2008; Madsen et al., 2014; Sherfy et al., 2011). The need for an evidence-based strategy is crucial, especially because issues regarding large grazing birds in many areas are changing focus from conservation to population regulation and crop protection (Amano, 2009; Pullin et al., 2004; Tombre et al., 2013), including by culling wildlife (Hothorn and Muller 2010; Kuijper, 2011). However, for large grazing birds, culling is often prevented by international legislative protection as well as ethical or practical obstacles.

Therefore, alternative measures need to be considered. Preventative measures currently used are scaring practices, such as propane cannons, flags and scarecrows, restricted lethal control aimed to scare birds from damage prone fields, and diversionary fields to which large grazing birds are attracted and left undisturbed to forage (Jensen et al., 2008; Tømmervik et al., 2005; Vickery and Gill, 1999). However, to make informed decisions and to implement effective measures, it is of fundamental importance to understand the probability of finding birds at a field under given conditions (Jensen et al., 2008; Pullin et al., 2004). Probability of finding birds at fields is influenced by crop type and crop stage as well as food abundance and quality (Amano et al., 2004; Anteau et al., 2011; Leito et al., 2008). Food abundance is strongly linked to harvest practices as waste grain becomes available at stubble fields and depletes over time due to consumption, decomposition or germination of grains (Lovvorn and Kirkpatrick, 1982). Moreover, distance from roost sites affects the probability of finding large grazing birds at a field as they trade energy gain against travel costs (Bautista et al., 1995; Gill, 1996; Jensen et al., 2008) with a clear daily pattern where birds feed on fields during the daytime and rest over night at roosting places (Bautista and Alonso, 2013).

In this study, we investigated the predictability of finding common cranes *G. grus* on arable fields at a staging site connected to an important wetland reserve. Common cranes are a suitable model species as, like other large grazing species they cause significant damage to crops, incurring considerable costs to society through loss of agricultural production and increasing compensation payments (Borad et al., 2001; Bouffard et al., 2005; McIvor and Conover, 1994). Moreover, this is not a local challenge as cranes are known to cause crop damage along their European flyways (Le Roy, 2010; Nowald, 2010). The challenges faced by conservation will affect many areas in Europe where migratory cranes, geese and swans forage in large numbers in agricultural landscapes surrounding important wetlands used for roosting (Alonso and Alonso, 1992; Leito et al., 2008; Vegvari and Tar, 2002). The aim of this study was to quantify the probability of common cranes (hereafter cranes) visiting fields in relation to their characteristics in order to develop evidence-informed management actions to decrease damage to agriculture. To investigate this question we tested the following variables in relation to the probability of finding cranes on fields: crop type, crop stage, distance to roost site, time since harvest, time of day and field size.

2. Methods

2.1. Study area

The study was located in Kvismaren (59°10′N/15°22′E), 15 km southeast of Örebro in the boreonemoral zone of south-central Sweden. The landscape is flat and dominated by highly productive agricultural land, well suited for cultivating cereals, grass, carrots and potatoes. Harvesting generally starts in August and continues until early October with variations depending on crop type and weather conditions, resulting in dynamic availability of crop types and crop stages (Fig. S1, Supporting information). The average precipitation in September is 50–75 mm, but 2012 was very rainy, with 75–100 mm precipitation during September (SMHI, 2014) which delayed the harvest. The core of the study area is a nature reserve consisting of two shallow eutrophic lakes, 2.5 km apart, surrounded by narrow strips of grazed wetlands. The area is an EU Natura 2000 Special Protection Area (SPA) and is designated under the Ramsar convention of wetlands. Kvismaren has been a key area for large grazing birds from March to November for the last 30 years, partly for breeding but especially during autumn migration staging for cranes and several goose species, mainly bean geese *Anser fabalis* and greylag geese *Anser anser.* The shallow lakes provide suitable roosting sites and the surrounding agricultural landscape provides good conditions for foraging on crops, waste grains and invertebrates as well as drinking water in ditches surrounding the fields (Anteau et al., 2011; Madsen, 1985a; Sugden et al., 1988). Cranes are present at Kvismaren from mid-August to early October, with a peak in 2009–2013 of 15,500–19,500 cranes. Such large concentrations can cause damage to growing crops (e.g. cultivated and unharvested crops) and economical losses for farmers in the area (Karlsson et al., 2013). Crop damage occurs during the entire vegetation period in newly sown fields and during growth, but predominantly in August to October just before harvest when large numbers of cranes arrive. Costs in terms of governmental subsidies for crop damage preventative measures and compensation for yield losses in Kvismaren, have ranged from 48,000 Euros (in 2010) to 150,000 Euros (in 2012) (Johanna M. Wikland, Örebro county administrative board, pers. comm.). Preventative measures involve scaring practices such as scarecrows and propane cannons,

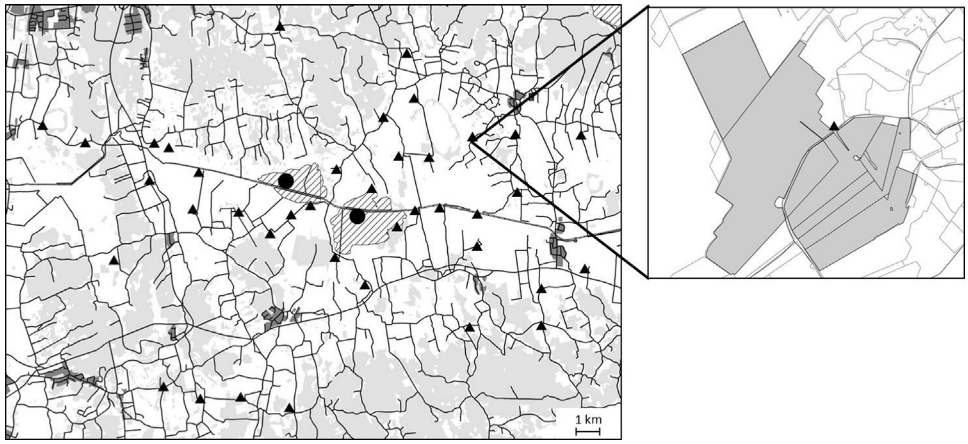

Fig. 1. A map (left) showing distribution of observation locations (triangles), roost sites (points), wetlands (striped), arable land (white) and other land (grey) in the study area, Kvismaren, Sweden. The detailed map (right) shows an example of arable fields surveyed from one of the observation locations (grey).

distributed on growing crops in the landscape (Kjellander et al., 2003; Hake et al., 2010). The level of scaring activity was hard to quantify as it was uncoordinated and undertaken by numerous farmers and land managers.

2.2. Field surveys

The field surveys were carried out during the staging period for cranes, from mid-August to the beginning of October 2012. The surveys were based on survey locations ($n = 39$) evenly distributed in the agricultural landscape surrounding the shallow lakes and within daily flight distance from nearest roost sites (11 km; defined by 19 GPS-tagged cranes within the study area; Nilsson and Månsson, unpublished data) and stratified to represent different distances to the roost sites (see Fig. 1). At each survey location, we surveyed all visible fields and parts of fields ($n = 244$) resulting in a total of 3221 observations. Fields were defined by using maps of administrative field borders from the Swedish Board of Agriculture. The median observed area per field was 5.3 ha, ranging from 0.2 to 73.3 ha. We divided the survey locations into two routes surveyed continuously, i.e. one route was done one day, and one the next, with a gap over weekends. The surveys were conducted from dawn to dusk and the start of the daily route was altered to vary the time of day each location was surveyed. The number of cranes per field was counted from each observation location with a telescope and time and date were noted. Crop type was obtained from the administrative database (SAM14, Swedish Board of Agriculture), whereas crop stage (stubble, growing crop etc.) was determined visually at each survey.

2.3. Data management

Crop types and stages were pooled into categories based on characteristics because some crop types had too few observations (Table 1). The distance to roost site was calculated from the center of each field to the center of the nearest roost site. Time since harvest for stubble fields was calculated from the first day when stubble was observed on a given field.

2.4. Statistical analysis

Cranes were spatially aggregated, resulting in a large proportion of zero counts within fields (88%). Thus, to account for the zero-inflated and over-dispersed distribution of the data, a number of generalized linear models were tested (Poisson, negative-binomial, zero-inflated, negative binomial zero-inflated and observation ID as random effect) (Harrison, 2014; Zuur et al., 2009) but without any satisfactory fit to the data. Thus, the data were analyzed as binomial (i.e. cranes were present or absent). Observed field area did not meet the criteria for normality and was log-transformed. Following graphical inspection, the time of day variable has a quadratic shape with the highest probability of cranes at approximately 11 am and in order to have a linear rather than a quadratic model, we set 11 am to time zero. Model selection was carried out according to Burnham and Anderson (2002) using the function 'dredge' (R package MuMIn: Barton, 2013). The best model was selected based on AIC and was used to model the associated fitted values and their 95% confidence intervals after repeated simulations ($n = 1000$) (R package arm: Gelman et al., 2014).

For the statistical analyses, two generalized linear mixed models with a binomial error structure and a logit link function were fitted (hereafter model 1 and 2) (R package lme4; Bates et al., 2015). Model 1 included crane presence (binomial) as response variable and crop stage (Table 1), distance to nearest roost site (km), time of day and observed field area (log(ha)) as explanatory variables. Observed field area was included merely to account for the fact that larger fields by chance have higher probability of crane presence. Field ID was added as a random factor to adjust for repeated surveys on each field.

For model 2, the dataset was subset to contain only stubble fields. Crop stage, as used in model 1, was replaced by stubble type (Table 1) and time since harvest was added as explanatory variable

Table 1
Crop stages as categorized in model 1.

Crop stage	Crop types included
Growing crop	Barley, beans, carrots, colza, corn, oat, peas, potatoes, protein mix, rape seed, rye, triticale, wheat
Stubble fields	Barley[1], oat[2], colza[4], peas[4], protein mix[4], rape seed[4], rye[4], triticale[4], wheat[3]
Grassland/grazing	Fallow, grassland, grazing ground
Bare soil	Newly sown cereals, harrowed fields, harvested potatoes, plowed fields

The crops were categorized in four stubble types in model 2 as [1]barley stubble, [2]oat stubble, [3]wheat stubble and [4]other stubble.

Table 2
Parameter estimates (logit) from the top models (Table S1, Supporting information) and standard errors of the binomial generalized mixed models based on crop stage in model 1 (categorical variable with levels stubble fields, growing crop, grassland/grazing ground and bare soil), stubble type in model 2 (categorical variable with levels barley, oat, other, wheat) and continuous variables distance to nearest roost site (km), observed field area$_{log}$ (ha) and time of day with fieldID fitted as a random factor. Model 2 also included time since harvest (days) as a continuous explanatory variable. The categorical estimates are in comparison with the intercept bare soil (model 1) and the intercept barley stubble (model 2). The estimates for the categorical explanatory variables represent intercepts and the estimates for continuous variables represent slopes.

Top ranked model	Explanatory variable	Estimate	S.E	*p*-value
Model 1	Bare soil (intercept)	−3.30	0.56	<0.01
	Growing crop	−0.24	0.43	0.58
	Grass and grazing	0.30	0.47	0.52
	Stubble field	1.66	0.43	<0.01
	Dist roost	−0.18	0.04	<0.01
	Observed field area$_{log}$	0.86	0.11	<0.01
	Time of day	−0.18	0.05	<0.01
Model 2	Barley stubble (intercept)	−1.03	0.54	0.06
	Oat stubble	−1.15	0.45	0.01
	Other stubble	−2.22	0.69	<0.01
	Wheat stubble	−0.55	0.31	0.07
	Dist roost	−0.14	0.06	0.02
	Observed field area$_{log}$	0.96	0.16	<0.01
	Time of day	−0.24	0.08	<0.01
	Time since harvest	−0.03	0.01	<0.01

to assess for how long stubble fields had been available. The remaining explanatory variables (distance to nearest roost site, time of day and observed field area) and the random factor (field ID), were the same in model 1 and 2 to account consistently for confounding effects.

Based on the best models selected by AIC, different scenario predictions with varying values of the variables were modelled. Three scenarios of distance to roost site were modeled: the maximum distance surveyed (10 km), 5 km and close to the roost sites (1 km). For time since harvest at stubble fields, we used day one (immediately after harvest), day seven and day 28 to model weekly differences. Time of day was set to 11 am as preliminary results showed that probability of crane presence at fields peaked at midday and observed field area was set to the median size 5.30 ha. All data analyses were done in R version 3.1.2 (R Core Team, 2015).

3. Results

3.1. Distribution of cranes on fields

In 88% of observations ($n = 3221$), the fields had no cranes, whereas the maximum number of birds on any one field was 1453. The median number of cranes was 23.5, when zero counts were excluded. Over 30 days of surveying, a total of 28,515 cranes were counted. At the beginning of the staging period, ‘growing crop’ was the dominant crop stage, although this changed over time to include more stubble fields and bare soils as harvesting and autumn sowing proceeded (Fig. S1, Supporting information). However, the area of grassland and grazing grounds was relatively constant over time (Fig. S1, Supporting information). Cranes used proportionally more growing crops in the beginning of the staging season, but progressively switched to higher proportional use of stubble fields as the staging season and harvest proceeded (Fig. S2, Supporting information).

3.2. Factors influencing probability of crane presence

According to model 1, the predicted presence of cranes was highest in stubble fields, with progressively lower estimates at grassland and grazing grounds, bare soil and growing crop (Table 2). The probability of crane presence declined with increasing distance to the nearest roost site (Fig. 2), and increased in larger fields. Time of day showed a linear relationship with the probability of crane presence being highest at around 11 am.

3.3. Stubble types and influence of time since harvest

Estimates from model 2 suggest that the highest probability of crane was in barley stubbles, followed by wheat, oat and other stubble. Probability declined with increasing time since harvest (Table 2, Fig. 3), despite a continuous increase in the total number of cranes in the area. As with Model 1, the probability of crane presence decreased with increasing distance to the nearest roost site, increased in larger fields and peaked at midday (Table 2).

3.4. Scenario predictions

We present different scenarios to illustrate probabilities of crane presence at different types of fields at different distances from roost sites and times since harvest.

Focusing on crop stage, a stubble field at 5 km from roost site has a predicted probability (95% CI) of presence of cranes of 0.25 (0.19–0.32) whereas it is much lower at grassland and grazing grounds 0.08 (0.05–0.11), bare soil 0.07 (0.03–0.14) and growing crops 0.05 (0.03–0.07). When considering distance to roost site, the predicted probability of cranes present at a stubble field 1 km from the roost site is 0.41 (0.29–0.54), whereas the probability under the same conditions at 10 km from roost site is only about a third of the probability at 1 km from the roost site at 0.12 (0.07–0.18). Predicted probability of crane presence can be remarkably high if all favorable factors are combined. For instance, a barley stubble field one day after harvest and close to the roost site (1 km), has a probability of crane presence of 0.60 (0.42–0.77). In contrast, a field with growing crop, 10 km away from roost site has a predicted probability of crane presence of only 0.02 (0.01–0.03), whereas a growing crop close to a roost site (1 km) has a predicted crane probability of 0.09 (0.06–0.15).

4. Discussion

Our study demonstrates that the probability of crane presence at fields is influenced by several factors affected by agricultural practices, such as crop stage, crop type and time since harvest. Also, distance to roost site plays an important role for crane probability at fields, which has implications for spatial allocation of agricultural and preventative measures to reduce crop damage. Thus, our results provide knowledge for management recommendations aimed at addressing the increasing damage of common cranes and potentially also other large grazing birds on agriculture.

We found that the probability of crane presence was higher on stubble fields compared to all other field types. Our predictions showed that crane presence close to the roost site was about three times higher at stubble fields than grassland, grazing grounds and bare soil and about five times higher than growing crop. This is most likely explained by easily accessible food in terms of waste grain (Lovvorn and Kirkpatrick, 1982; Shimada, 2002; Sugden et al., 1988). Likewise, declining probability with time since harvest at stubble fields can be explained by decreasing availability of waste grain due to consumption by large grazing birds, smaller grainivorous birds and rodents (Galle et al., 2009; Pinkert et al., 2002). Food availability further declines due to continuous sprouting of grains after harvest as cranes reject germinated grains (Bautista and Alonso, 2013). In our study area, scaring practices occur but are hard to quantify because

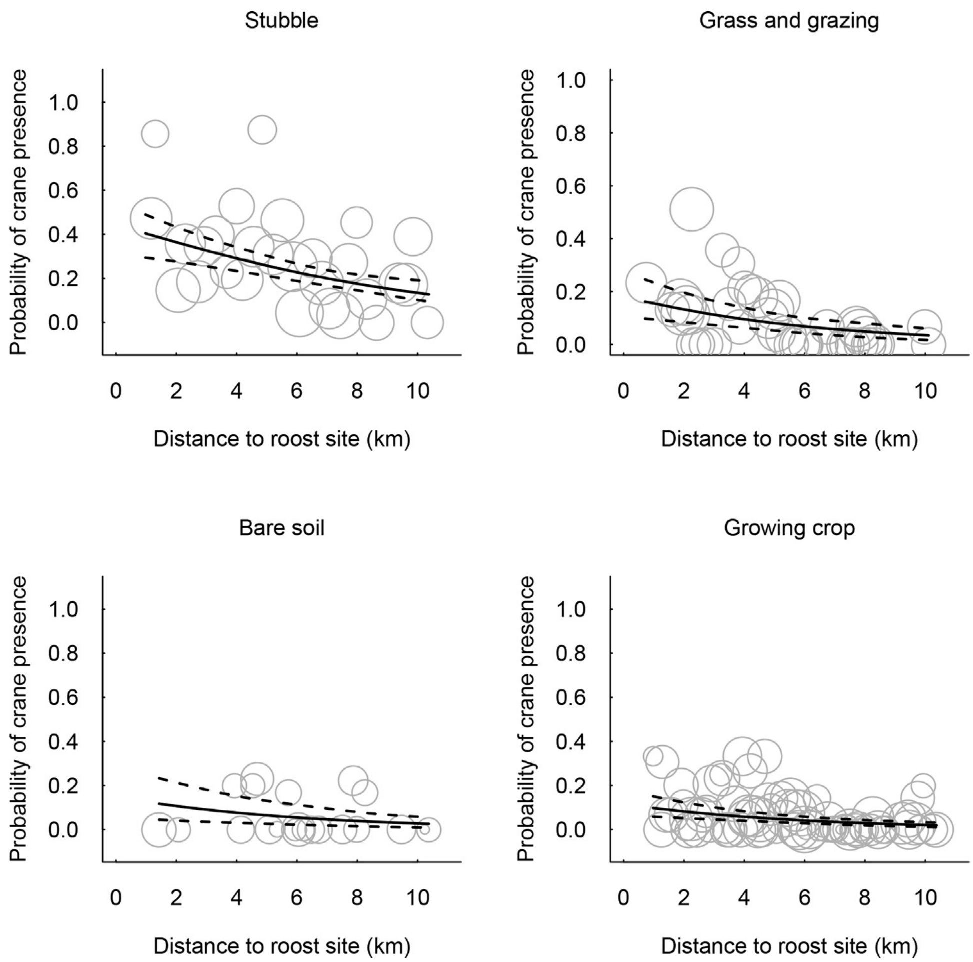

Fig. 2. Probabilities of crane presence in relation to distance to nearest roost site at stubble fields, grassland and grazing ground, bare soil and growing crops. Predictions (solid lines) and confidence intervals (95%; dashed lines) are derived from 1000 model simulations using the top model estimates (Table 2) from the first step binomial generalized linear mixed model. For the predictions, time of day is kept constant to 0 (11 AM) and observed field area to the median size (5.30 ha) in the predictions. Circles are summarized data points, the circle size is linearly related to the number of data points.

they are undertaken by individual farmers. Scaring solely occurs on growing crops and newly sown fields (Hake et al., 2010), which may explain some of the variation in our data and potentially also cause an underestimation of the probability of crane presence at these crop stages. Moreover, beside the explanatory variables included in our study, other factors such as human disturbance and predator avoidance may affect spatial distribution of large grazing birds (Rees et al., 2005; Rosin et al., 2012; Tombre et al., 2013). These variables can potentially also affect the probability of crane presence at fields and may therefore add further unexplained variation to the field use of cranes and thus we suggest that these variables are considered in future studies (Table 3). Still, our findings are in line with other studies showing that harvested fields in general and cereal stubbles in particular, are attractive for large grazing birds during staging (Gill, 1996; Rosin et al., 2012; Sugden et al., 1988). Grassland and grazing grounds had a relatively high probability of crane presence despite absence of waste grain, presumably as they offer invertebrates as an alternative food resource (Anteau et al., 2011). According to our results, stubble fields of barley had the highest probability of crane presence followed by wheat, oat and other stubble fields which is supported by other studies on large grazing birds (Madsen, 1985c; McIvor and Conover, 1994; Sugden et al., 1988). We have not considered activity of the cranes when observed on the fields, however, earlier studies show that the majority (up to 85%) of daytime is spent on foraging (Alonso and Alonso, 1992). We therefore assume that cranes present on fields are foraging and thereby also pose a potential risk of crop damage on growing crops and newly sown fields.

We demonstrated that crane presence declined with increasing distance to nearest roost sites, also documented in numerous previous studies on large grazing birds (Franco et al., 2000; Gill, 1996; Sugden et al., 1988). This pattern is expected, and presumably quite general, as large grazing birds should optimize their net energy intake by optimizing the trade-off between food availability and flight distance. Thus, for a given level of food availability fields close to roost sites are more attractive (Bautista et al., 1995).

Crane presence on fields was highest around midday and lowest in early mornings and late afternoons. Cranes leave roost sites in large groups at dawn, occur in smaller groups in fields around noon and again aggregate close to roost sites during the afternoon before night roosting. Similarly, Chudzinska et al., (2013) showed that presence of pink-footed geese peaks during midday. However, other studies have documented contrasting patterns for large grazing birds, with higher feeding activity in mornings and afternoons than during midday (Bautista and Alonso, 2013; Owen, 1972; Rees et al., 2005).

4.1. Management implications

An evidence-based crop damage preventative strategy supported by our results and previous scientific knowledge can reduce the risk of damage to agricultural fields and ultimately contribute

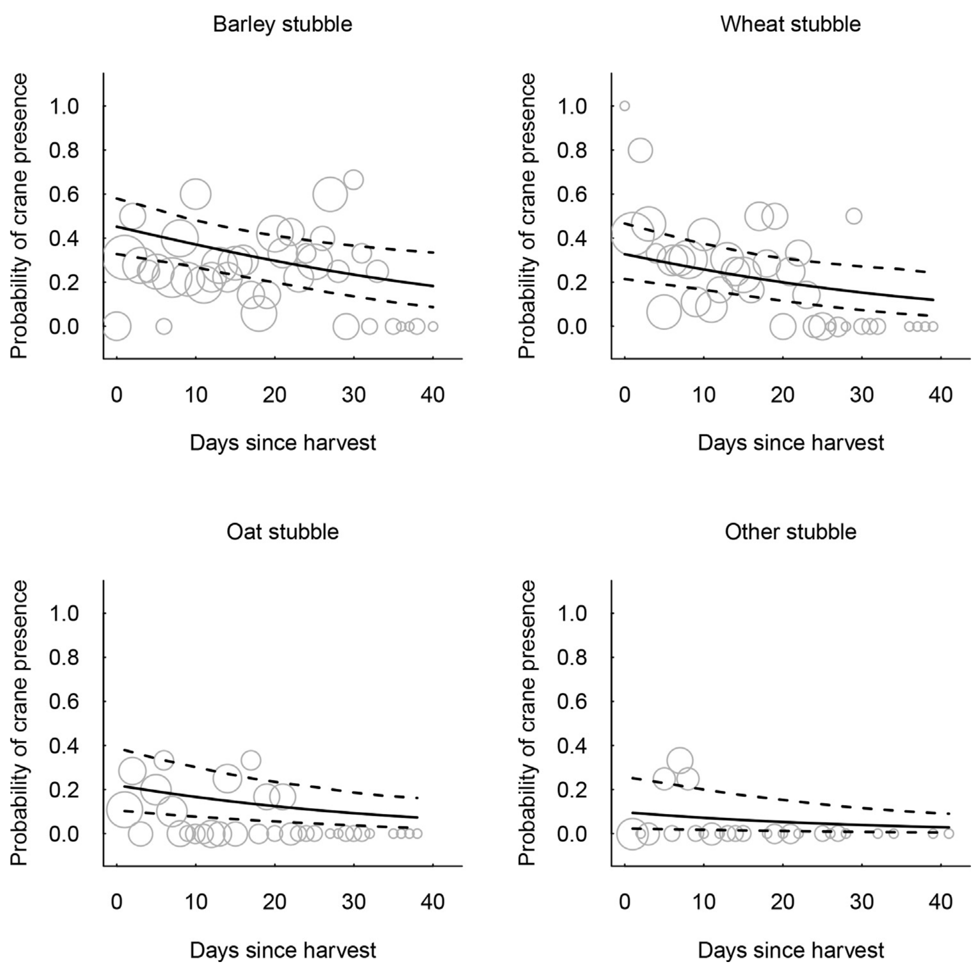

Fig. 3. Probabilities of crane presence at barley, wheat, oat and other stubble in relation to time since harvest. Predictions (solid lines) and it's confidence intervals after 1000 model simulations (95%; dashed lines) are derived from the top model estimates (Table 2) from the second binomial generalized linear mixed model. The time of day are kept constant to 0 (11 am), the observed field area to the median size (5.30 ha) and the distance to roost to its mean (5.70 km) in the predictions. Circles are summarized data points, circle size is linearly related to the number of data points.

to management of large grazing birds and agriculture. This needs to be achieved with a framework that acknowledges the current international legislation prohibiting the hunting of large grazing birds and the promotion of wetland protection for the conservation of bird diversity.

We have shown that there is a potential risk of damage to growing crops, but also at newly sown fields in the agricultural landscape surrounding protected wetlands. Importantly, our results illustrate how the probability of crane presence is influenced by the characteristics and location of fields (i.e., crop type and crop stage, time after harvest, and distance to roost site) which has the potential to improve crop damage preventative strategies. For instance, presence of large grazing birds decreases considerably with distance to roost site, suggesting that intensified management efforts in the vicinity of roost sites would be justified. Such strategies should focus on providing stubble fields as diversionary food to steer the birds away from growing crops and newly sown fields. Stubbles should be provided when birds arrive for staging and be left unplowed until the end of the staging period. This can be achieved by careful crop rotation planning of winter-sown versus spring-sown crops to alternate timing of harvest and plowing. Similar measures have successfully reduced crop damage by geese in Japan (Amano et al., 2007). Stubble fields should preferably be combined with measures to make fields with growing crops less attractive either by scaring or by cultivating less attractive crops. As agricultural systems are relatively dynamic due

Table 3
Factors (predator avoidance and human disturbance) that were not considered in our study that could affect the field use of large grazing birds. Examples of observed effects of these variables on field use.

Factor	Example of variable to study	Effect on field use
Predator avoidance	Distance to forest	Negatively related[a]
Human disturbance	Scaring intensity	Negatively related/no effect[b,c]
Human disturbance	Distance to roads	Negatively related[d,e]
Human disturbance	Distance to pedestrians, bicycles	Negatively related[d]

[a] Rosin et al., 2012.
[b] Tombre et al., 2013.
[c] Sugden et al., 1988.
[d] Rees et al., 2005.
[e] Madsen, 1985b.

to yearly crop rotation, such strategies could be applied in local management. However, crop rotation and agricultural practices are dependent on soil- and climatic conditions, national political schemes and international conventions (e.g., the CAP) that may restrict flexibility (Cope et al., 2003; Henle et al., 2008). Changes in crop choice may also lead to higher costs that could potentially be compensated by governmental subsidies (Hake et al., 2010) to minimize inequalities among farmers and to increase the acceptance for adapting the agriculture practices to the birds and their management at a landscape scale. However, further research is still needed to assess the required area of stubble fields to fulfill the bird's resource needs, as well as to evaluate the long-term consequences on the population size and agricultural practices of providing such resources (Klaassen et al., 2008; Madsen et al., 2014; Vickery et al., 1994). Our results and recommendations provide insights for wide application in areas where large grazing birds aggregate in large numbers along their flyway (e.g. during staging and wintering periods). However, the strategies may need local adaptation (Sugden et al., 1988). Implementation of efficient strategies is particularly critical when staging sites coincide with important wetland reserves. Strategies should therefore preferably be applied in buffer zones when protecting wetland areas, similar to procedures around many wildlife reserves and sensitive forest environments (Bamford et al., 2014; Correll, 2005; Wells and Brandon, 1993). Such an approach could help not only to protect and fulfill the needs of large grazing birds but also to support farmers in the neighboring landscape.

5. Conclusions

Given the increasing populations of large grazing birds and the existing framework of international conventions and prohibited culling, there is a need for preventative strategies to reduce crop damage. Our results demonstrate that such management strategies should focus on providing cereal stubbles as diversionary fields in combination with scaring practices on growing crops and newly sown fields and especially close to wetland roosting sites where the probability of crane presence is high. Stubble field availability can be achieved by careful crop rotation planning. Therefore we suggest that crop rotation and time of harvest should be added to flyway management plans recently developed for some large grazing bird species to facilitate stable co-existence between conservation practices and agricultural interests.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2015.12.021.

References

Alonso, J.A., Alonso, J.C., Veiga, J., 1983. Winter feeding of the crane in cereal farmland at Gallocanta, Spain. Wildfowl 35, 119–131.
Alonso, J.C., Alonso, J.A., 1992. Daily activity and intake rate patterns of wintering common cranes *Grus grus*. Ardea 80, 343–351.
Amano, T., 2009. Conserving bird species in Japanese farmland: past achievements and future challenges. Biol. Conserv. 142, 1913–1921. doi:http://dx.doi.org/10.1016/j.biocon.2008.12.025.
Amano, T., Ushiyama, K., Fujita, G., Higuchi, H., 2004. Factors affecting rice grain density unconsumed by white-fronted geese in relation to wheat damage. Agric. Ecosyst. Environ. 102, 403–407. doi:http://dx.doi.org/10.1016/j.agee.2003.09.021.
Amano, T., Ushiyama, K., Fujita, G.O., Higuchi, H., 2007. Predicting grazing damage by white-fronted geese under different regimes of agricultural management and the physiological consequences for the geese. J. Appl. Ecol. 44, 506–515. doi:http://dx.doi.org/10.1111/j.1365-2664.2007.01314.x.
Amano, T., Ushiyama, K., Higuchi, H., 2008. Methods of predicting risks of wheat damage by white-fronted geese. J. Wildl. Manage. 72, 1845–1852. doi:http://dx.doi.org/10.2193/2007-463.
Anteau, M.J., Sherfy, M.H., Bishop, A.A., 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. J. Wildl. Manage. 75, 1004–1011. doi:http://dx.doi.org/10.1002/jwmg.135.
Bamford, A.J., Ferrol-Schulte, D., Wathan, J., 2014. Human and wildlife usage of a protected area buffer zone in an area of high immigration. Oryx 1–10 doi:http://dx.doi.org/10.1017/s0030605313000215.
Barton, K., 2013. MuMIn: Multi-model Inference. R Package Version 1.15.1. R Project for Statistical Computing, Vienna, Austria. http://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf.
Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. lme4: Linear mixed-effects models using Eigen and S4 [WWW Document]. R Packag. version 1. 1-8. URL http://cran.r-project.org/package=lme4. (accessed 8.03.2015).
Bautista, L.M., Alonso, J.C., 2013. Factors influencing daily food-intake patterns in birds: a case study with wintering common cranes. Condor 115, 330–339. doi:http://dx.doi.org/10.1525/cond.2013.120080.
Bautista, L.M., Alonso, J.C., Alonso, J.A., 1995. A field-test of ideal free distribution in flock-feeding common cranes. J. Anim. Ecol. 64, 747–757.
Borad, C.K., Mukherjee, A., Parasharya, B.M., 2001. Damage potential of Indian sarus crane in paddy crop agroecosystem in Kheda district Gujarat, India. Agric. Ecosyst. Environ. 86, 211–215.
Bouffard, S.H., Cornely, J.E., Goroshko, O.A., 2005. Crop depredations by cranes at Daursky state biosphere reserve, Siberia. Proceedings North American Crane Workshop 9, Sacramento, Californa, USA, pp. 145–149.
Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: a practical information-theoretic approach. Ecol. Modell. doi:http://dx.doi.org/10.1016/j.ecolmodel.2003.11.004.
Chudzinska, M., Madsen, J., Nabe-Nielsen, J., 2013. Diurnal variation in the behaviour of the pink-footed goose (*Anser brachyrhynchus*) during the spring stopover in Trøndelag, Norway. J. Ornithol. 154, 645–654. doi:http://dx.doi.org/10.1007/s10336-012-0927-y.
Cope, D.R., Pettifor, R.A., Griffin, L.R., Rowcliffe, J.M., 2003. Integrating farming and wildlife conservation: the Barnacle Goose Management Scheme. Biol. Conserv. 110, 113–122.
Correll, D.L., 2005. Principles of planning and establishment of buffer zones. Ecol. Eng. 24, 433–439. doi:http://dx.doi.org/10.1016/j.ecoleng.2005.01.007.
Dickman, A.J., 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. Anim. Conserv. 13, 458–466. doi:http://dx.doi.org/10.1111/j.1469-1795.2010.00368.x.
Fox, A.D., Ebbinge, B.S., Mitchell, C., Heinicke, T., Aarvak, T., Colhoun, K., Clausen, P., Dereliev, S., Farago, S., Koffuberg, K., Kruckenberg, H., Loonen, M.J.J.E., Madsen, J., Mooij, J., Musil, P., Nilsson, L., Pihl, S., van der Jeugd, H., 2010. Current estimates of goose population sizes in western Europe, a gap analysis and an assessment of trends. Ornis Svecica. 20, 115–127.
Fox, A.D., Madsen, J., 1997. Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. J. Appl. Ecol. 34, 1–13.
Franco, A.M.A., Brito, J.C., Almeida, J., 2000. Modelling habitat selection of common cranes *Grus grus* wintering in Portugal using multiple logistic regression. Ibis (Lond. 1859) 142, 351–358.
Galle, A.M., Linz, G.M., Homan, H.J., Bleier, W.J., 2009. Avian use of harvested crop fields in North Dakota during spring migration. West. North Am. Nat. 69, 491–500. doi:http://dx.doi.org/10.3398/064.069.0409.
Gelman, A., Su, Y.-S., Yajima, M., Hill, J., Pittau, M.G., Kerman, J., Zheng, T., Dorie, V., 2014. Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press.
Gill, J.A., 1996. Habitat choice in pink-footed geese: quantifying the constraints determining winter site use. J. Appl. Ecol. 33, 884–892.
Hake, M., Mansson, J., Wiberg, A., 2010. A working model for preventing crop damage caused by increasing goose populations in Sweden. Ornis Svecica 20, 225–233.
Harris, J., Mirande, C., 2013. A global overview of cranes: status, threats and conservation priorities. Chin. Birds 4, 189–209. doi:http://dx.doi.org/10.5122/cbirds.2013.0025.
Harrison, X.A., 2014. Using observation-level random effects to model overdispersion in count data in ecology and evolution. PeerJ 2, e616. doi:http://dx.doi.org/10.7717/peerj.616.
Heinrich, J.W., Craven, S.R., 1992. The economic-impact of canada geese at the Horicon marsch Wisconsin. Wildl. Soc. Bull. 20, 364–371.
Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R.F.A., Niemelä, J., Rebane, M., Wascher, D., Watt, A., Young, J., 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—a review. Agric. Ecosyst. Environ. 124, 60–71. doi:http://dx.doi.org/10.1016/j.agee.2007.09.005.

Hothorn, T., Muller, J., 2010. Large-scale reduction of ungulate browsing by managed sport hunting. For. Ecol. Manage. 260, 1416–1423. doi:http://dx.doi.org/10.1016/j.foreco.2010.07.019.

Jensen, R.A., Wisz, M.S., Madsen, J., 2008. Prioritizing refuge sites for migratory geese to alleviate conflicts with agriculture. Biol. Conserv. 141, 1806–1818. doi:http://dx.doi.org/10.1016/j.biocon.2008.04.027.

Jongman, R.H.G., 2002. Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landscape Urban Plan. 58, 211–221. doi:http://dx.doi.org/10.1016/s0169-2046(01) 00222-5.

Karlsson, J., Danell, A., Månsson, J., Svensson, L., Hellberg, R., 2013. Viltskadestatistik 2012-skador av fredat vilt på tamdjur, hundar och gröda. Riddarhyttan .

Kjellander, P., Hake, M., Ahlqvist, I., Sjöstedt, E., Levin, M., 2003. Tranor vid Kvismaren–antalsvariationer, val av födosöksområden och skadeförebyggande åtgärder. Riddarhyttan .

Klaassen, M., Bauer, S., Madsen, J., Possingham, H., 2008. Optimal management of a goose flyway: migrant management at minimum cost. J. Appl. Ecol. 45, 1446–1452. doi:http://dx.doi.org/10.1111/j.1365-2664.2008.01532.x.

Kleijn, D., Cherkaoui, I., Goedhart, P.W., van der Hout, J., Lammertsma, D., 2014. Waterbirds increase more rapidly in Ramsar-designated wetlands than in unprotected wetlands. J. Appl. Ecol. 51, 289–298. doi:http://dx.doi.org/10.1111/1365-2664.12193.

Kuijper, D.P.J., 2011. Lack of natural control mechanisms increases wildlife-forestry conflict in managed temperate European forest systems. Eur. J. For. Res. 130, 895–909. doi:http://dx.doi.org/10.1007/s10342-011-0523-3.

Lane, S.J., Azuma, A., Higuchi, H., 1998. Wildfowl damage to agriculture in Japan. Agric. Ecosyst. Environ. 70, 69–77. doi:http://dx.doi.org/10.1016/s0167-8809(98) 00114-5.

Le Roy, E., 2010. What has been done in the Champagne-Ardenne to prevent crane damages on farmlands since 2004. In: Nowald, G., Alexander, W., Fanke, J., Weinhardt, E., Donner, N. (Eds.), Proceedings of the VIIth European crane conference breeding, resting, migration and biology. Stralsund, Germany, pp. 53–56.

Leito, A., Truu, J., Ounsaar, M., Sepp, K., Kaasik, A., Ojaste, I., Magi, E., 2008. The impact of agriculture on autumn staging Eurasian cranes (*Grus grus*) in Estonia. Agric. Food Sci. 17, 53–62.

Lorenzen, B., Madsen, J., 1986. Feeding by geese in the Filsø farmland, Denmark, and the effect of grazing on yield structure of spring barley. Holarctic Ecol. 9, 305–311.

Lovvorn, J.R., Kirkpatrick, C.M., 1982. Field use by staging Eastern greater sandhill cranes. J. Wildl. Manage. 46, 99–108.

MacMillan, D., Hanley, N., Daw, M., 2004. Costs and benefits of wild goose conservation in Scotland. Biol. Conserv. 119, 475–485. doi:http://dx.doi.org/10.1016/j.biocon.2004.01.008.

MacMillan, D.C., Leader-Williams, N., 2008. When successful conservation breeds conflict: an economic perspective on wild goose management. Bird Conserv. Int. 18, S200–S210. doi:http://dx.doi.org/10.1017/s0959270908000282.

Madsen, J., 1985a. Habitat selection of farmland feeding geese in West Jutland, Denmark : an example of a niche shift. Ornis Scand. 16, 140–144.

Madsen, J., 1985b. Impact of disturbance on field utilization of pink-footed geese in West Jutland, Denmark. Biol. Conserv. 33, 53–63.

Madsen, J., 1985c. Relations between change in spring habitat selection and daily energetics of pink-footed geese *Anser brachyrhynchus*. Ornis Scand. 16, 222–228.

Madsen, J., Bjerrum, M., Tombre, I.M., 2014. Regional management of farmland feeding geese using an ecological prioritization tool. Ambio 43, 801–809. doi:http://dx.doi.org/10.1007/s13280-014-0515-x.

Madsen, J., Williams, J.H., 2012. International Species Management Plan for the Svalbard Population of the Pink-footed Goose *Anser Brachyrhynchus*, Bonn, Germany.

McIvor, D.E., Conover, M.R., 1994. Impact of greater sandhill cranes foraging on corn and barley crops. Agric. Ecosyst. Environ. 49, 233–237.

Mewes, W., Prange, H., Nowald, G., 2010. Current status of the common crane in Germany - breeding, resting and colour banding. In: Nowald, G., Weber, A., Fanke, J., Weinhardt, E., Donner, N. (Eds.), Proceedings of the VIIth Crane Conference, , pp. 22–29.

Nilsson, L., 2002. Numbers of mute swans and Whooper swans in Sweden, 1967-2000. Waterbirds 25, 53–60.

Nowald, G., 2010. Cranes and people: Agriculture and tourism. In: Harris, J. (Ed.), Cranes, Agriculture and Climate Change. Muraviovka Park, Russia, pp. 60–64.

Owen, M., 1972. Some factors affecting food intake and selection in white-fronted geese. J. Anim. Ecol. 41, 79. doi:http://dx.doi.org/10.2307/3507.

Pinkert, M., Pinkert, M.K., Meerbeek, J.R., Scholten, G.D., Jenks, J.A., 2002. Impact of crop harvest on small mammal populations in Brookings County, South Dakota. Proc. S. Dak. Acad. Sci. 81, 39–45.

Pullin, A.S., Knight, T.M., Stone, D.A., Charman, K., 2004. Do conservation managers use scientific evidence to support their decision-making? Biol. Conserv. 119, 245–252. doi:http://dx.doi.org/10.1016/j.biocon.2003.11.007.

R Core Team, 2015. R: a language and environment for statistical computing

Redpath, S.M., Gutiérrez, R.J., Wood, K.A., Young, J.C., 2015. Conflicts in conservation-navigating towards solutions. British Ecological Society. Cambridge University Press, Cambridge.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D.C., Watt, A., Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. Trends Ecol. Evol. 28, 100–109. doi:http://dx.doi.org/10.1016/j.tree.2012.08.021.

Rees, E.C., Bruce, J.H., White, G.T., 2005. Factors affecting the behavioural responses of whooper swans (*Cygnus cygnus*) to various human activities. Biol. Conserv. 121, 369–382. doi:http://dx.doi.org/10.1016/j.biocon.2004.05.009.

Rosin, Z.M., Skorka, P., Wylegala, P., Krakowski, B., Tobolka, M., Myczko, L., Sparks, T.H., Tryjanowski, P., 2012. Landscape structure, human disturbance and crop management affect foraging ground selection by migrating geese. J. Ornithol. 153, 747–759. doi:http://dx.doi.org/10.1007/s10336-011-0791-1.

Salvi, A., 2010. Eurasian cranes (*Grus grus*) and agriculture in France. In: Harris, J. (Ed.), Cranes, Agriculture and Climate Change. Muraviovka Park, Russia, pp. 65–70.

Sherfy, M.H., Anteau, M.J., Bishop, A.A., 2011. Agricultural practices and residual corn during spring crane and waterfowl migration in Nebraska. J. Wildl. Manage. 75, 995–1003. doi:http://dx.doi.org/10.1002/jwmg.157.

Shimada, T., 2002. Daily activity pattern and habitat use of greater white-fronted geese wintering in Japan: factors of the population increase. Waterbirds 25, 371–377. doi:http://dx.doi.org/10.1675/1524-4695(2002) 025[0371:DAPAHU]2.0.CO;2.

SMHI, 2014. Swedish Meteorological Institute [WWW Document]. URL http://www.smhi.se/klimatdata/meteorologi/2.1353/monYrTable.php?month=9&par=nbd (accessed 11.25.2014).

Stoate, C., Boatman, N., Borralho, R., Carvalho, C.R., Snoo, G.R.d., Eden, P., 2001. Ecological impacts of arable intensification in Europe. J. Environ. Manage. 63, 337–365. doi:http://dx.doi.org/10.1006/jema.2001.0473.

Sugden, L.G., Clark, R.G., Woodsworth, E.J., Greenwood, H., 1988. Use of cereal fields by foraging sandhill cranes in Saskatchewan. J. Appl. Ecol. 25, 111–124.

Tombre, I.M., Eythórsson, E., Madsen, J., 2013. Towards a solution to the goose-agriculture conflict in North Norway, 1988–2012: the interplay between policy, stakeholder influence and goose population dynamics. PLoS One 8, e71912. doi:http://dx.doi.org/10.1371/journal.pone.0071912.

Tømmervik, I.M., Madsen, J., Tømmervik, H., Haugen, K.P., Eythorssón, E., 2005. Influence of organised scaring on distribution and habitat choice of geese on pastures in Northern Norway. Agric. Ecosyst. Environ. 111, 311–320. doi:http://dx.doi.org/10.1016/j.agee.2005.06.007.

Vegvari, Z., Tar, J., 2002. Autumn roost site selection by the common crane *Grus grus* in the Hortobagy National Park, Hungary, between 1995 and 2000. Ornis Fenn 79, 101–110.

Vickery, J.A., Gill, J.A., 1999. Managing grassland for wild geese in Britain: a review. Biol. Conserv. 89, 93–106.

Vickery, J.A., Watkinson, A.R., Sutherland, W.J., 1994. The solution to the Brent goose problem—an economic-analysis. J. Appl. Ecol. 31, 371–382.

Wells, M., Brandon, K., 1993. The principles and practice of buffer zones and local participation in biodiversity conservation. Ambio 22, 157–162.

Woodroffe, R., 1998. Edge effects and the extinction of populations inside protected areas. Science (80-.) 280, 2126–2128. doi:http://dx.doi.org/10.1126/science.280.5372.2126.

Zuur, A., Ieno, E.N., Walker, N., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and extensions in ecology with R. Springer Sci. Bus. Media .